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Mechanizing Cone Collection of Black Spruce in Ontario

K. W. Horton

A Joint Report of the Great Lakes Forest Research Centre
and the Ontario Ministry of Natural Resources

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MECHANIZING CONE COLLECTION OF BLACK SPRUCE IN ONTARIO

K.W. HORTON[1]

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FOREST RESEARCH CENTRE AND THE ONTARIO
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ABSTRACT

This report summarizes 15 years of cooperative research, equipment development and operational testing of the mechanization of black spruce *(Picea mariana* [Mill.] B.S.P.) cone collection. Various machines for stripping cone-laden branches from tops, for separating cones from twigs and needles and for handling materials are described. Optional operating systems for a variety of logging methods, locations and labor circumstances are discussed, together with costs of different operational phases.

RÉSUMÉ

Le présent rapport résume 15 années de recherche, de mises au point d'engins et d'essais en grand, réalisés en collaboration, sur la mécanisation de la récolte des cônes de l'épinette noire *(Picea mariana* [Mill.] B.S.P.). On décrit divers engins qui coupent les branches chargées de cônes du sommet des arbres, qui séparent les cônes des rameaux et des aiguilles et qui manutentionnent les cônes. On discute de variantes adaptées à une foule de stations, de méthodes et de conditions d'exploitation, ainsi que des coûts liés aux diverses étapes de l'exploitation.

FOREWORD

This report, commissioned by the Great Lakes Forest Research Centre, chronicles an exemplary case of forest research working hand in hand with forestry operations to solve a complex problem--the development of efficient methods of collecting large amounts of black spruce seed for regeneration. It spans 15 years of cooperative effort by federal and provincial foresters, private engineers and consultants, mechanics, technicians and forest workers. Most of this work took place between 1979 and 1983, with funding provided by the Canada-Ontario Forest Management Subsidiary Agreement. The solution itself is complex, involving an array of optional machinery and operating systems to match diverse field situations. A dozen reports, both published and unpublished, were synopsized to present this story. This summary deals only with the collection of cones from slash, and is not concerned with parallel efforts made to test equipment and techniques for collecting cones from standing trees.

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SEED REQUIREMENTS

Reforestation activity is expanding rapidly throughout Canada, increasing the requirements for seed and for more efficient seed collection methods. In Ontario, black spruce (*Picea mariana* [Mill.] B.S.P.) is the foremost tree species, comprising some 48% of the coniferous growing stock and occupying 41% (17.4 million ha) of the productive forest land--45% of it on peatlands (Ketcheson and Jeglum 1972). The ever increasing demand for black spruce pulpwood and the generally low levels of natural regeneration in cutover areas emphasize the need for effective regeneration methods (Fraser and Haavisto 1972). These include direct seeding and planting, both of which have large seed requirements.

Smith[2] estimated that projected black spruce seed requirements would necessitate the annual collection of as many as 15,000 hl of new cones, and would involve over 400,000 trees. However, good cone crops occur four years apart on the average, and consequently cone collection must be increased greatly during those occurrences. On the other hand, since black spruce cones are semi-serotinous, they accumulate for years on the tops, retaining appreciable amounts of viable seed (Haavisto 1975).

These considerations point to the desirability of mechanizing cone collection, thereby reducing the dependence on good seed years and on the large and uncertain labor force needed for hand picking. It is presumed that efficient mechanized methods of cone collection would increase production of seed from superior stands and decrease overall seed costs.

SEED PRODUCTION

Black spruce has semi-serotinous cones which can remain on the tree tops for more than 25 years, retaining some seed (Haavisto 1975). Good cone crops generally occur at intervals of 2 to 6 years but locally can be 10 or more years apart, depending on such factors as weather and spruce budworm outbreaks[3]. Dominant trees can produce more than 1,000 cones in good crop years and may retain up to 14,000 cones. The average number of cones per tree retained in all crown classes is about 7,500 (Haavisto 1975). Some 3.6 L of cones are produced per tree in a good year (Anon. 1977).

Vincent (1966) found that the number of seeds extracted per cone declined from 24 to 7 between years 1 and 5 (cone age) but the extracted seeds represented less than half of the contained seeds, an indication that extraction is difficult. On average, only 28% of the seed was sound and its germination rate was 50%. Higher germination rates--over 80%--have been recorded (Haig 1969). Haavisto (1975) found only 2 to 4 viable seeds per cone, about one-third of the contained seed. Viability averaged 53% in seed from cones 1 to 5 years old,

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[2] Smith, E.P. 1979. Methods study on the collection of black spruce cones from tops. Heathwood Eng. Assoc., Kirkland Lake, Ont. (unpubl. rep.)

[3] Miller, B. 1982. A report on the 1981-82 mechanical cone harvesting program in Kapuskasing District. Ont. Min. Nat. Resour., Kapuskasing District. (unpubl. rep.)

dropped rapidly in cones 6 to 10 years old and was negligible in cones older than 20 years. These studies indicate that it is feasible to collect cones as old as 5 years, since they retain more than half of their viable seed to that age.

It is recommended that black spruce cones be collected between 8 September and 1 December in Ontario (Anon. 1977). However, Haavisto's (1975) study indicated that 76% of the viable seed dispersed naturally throughout the year falls in the months of March to May, and this suggests that the collection period could be extended to early March.

PROTOTYPE CONE HARVESTERS

In view of the potential advantages of mechanical cone collection, the Great Lakes Forest Research Centre (GLFRC) of the Canadian Forestry Service took the initiative in attempting to develop the necessary equipment. In 1967, Horton Forestry Services Limited of R.R. #4, Stouffville, Ontario was contracted to design, construct and test a machine for separating cones of black spruce and jack pine *(Pinus banksiana* Lamb.) from slash and to undertake operational trials comparing the efficiency of manual and mechanical cone collection (Haig 1969). The first prototype, termed "Mechanoconer I", was an adapted agricultural threshing machine mounted on and powered by a 1-ton truck. A second version, developed independently by the contractor, was a modified early model Case combine (Fig. 1). Frank Robson, a veteran farm equipment mechanic, modified and rigged the machines. In both models, cone-bearing slash was fed past revolving, toothed cylinders that stripped cones from branches. Cones were then separated from broken foliage by a series of vibrating screens and an air blast. In "Mechanoconer II" snapping rolls from a corn picker attachment placed at the infeed provided a preliminary cone-separating function.

Although both prototype machines required frequent repairs and some adjustments, trials proved that mechanical cone separation was feasible and could be much faster than hand picking. Machine collection of cones, including gathering and lopping of tops but excluding breakdown time, was five times faster than hand picking (about 35 L vs 7 L per man-hour). (Note: 1 hl = 100 L.)

The machine production rate was 3.13 hl per machine hour with a heavy current crop and 2.44 hl with a very light current crop. Offsetting much of this cone production advantage was the fact that the yield of seed per litre of cones produced mechanically was only one-third that of hand picking, which was confined to the current year's cones. Germination rates were comparable--77% for mechanized and 83% for manual collections. In balance it was proved that mechanical cone processing could realize a significant saving in black spruce seed costs. The largest cost factor was in gathering cone-laden tops and branches at the roadside.

CONE SEPARATION OPTIONS

During the 1970s Haavisto (1979, 1980) and others tested, on a small scale, various devices for collecting and separating black spruce cones, including hand rakes, peat shredders, hammermills and chain flails. Then in 1979 a concerted

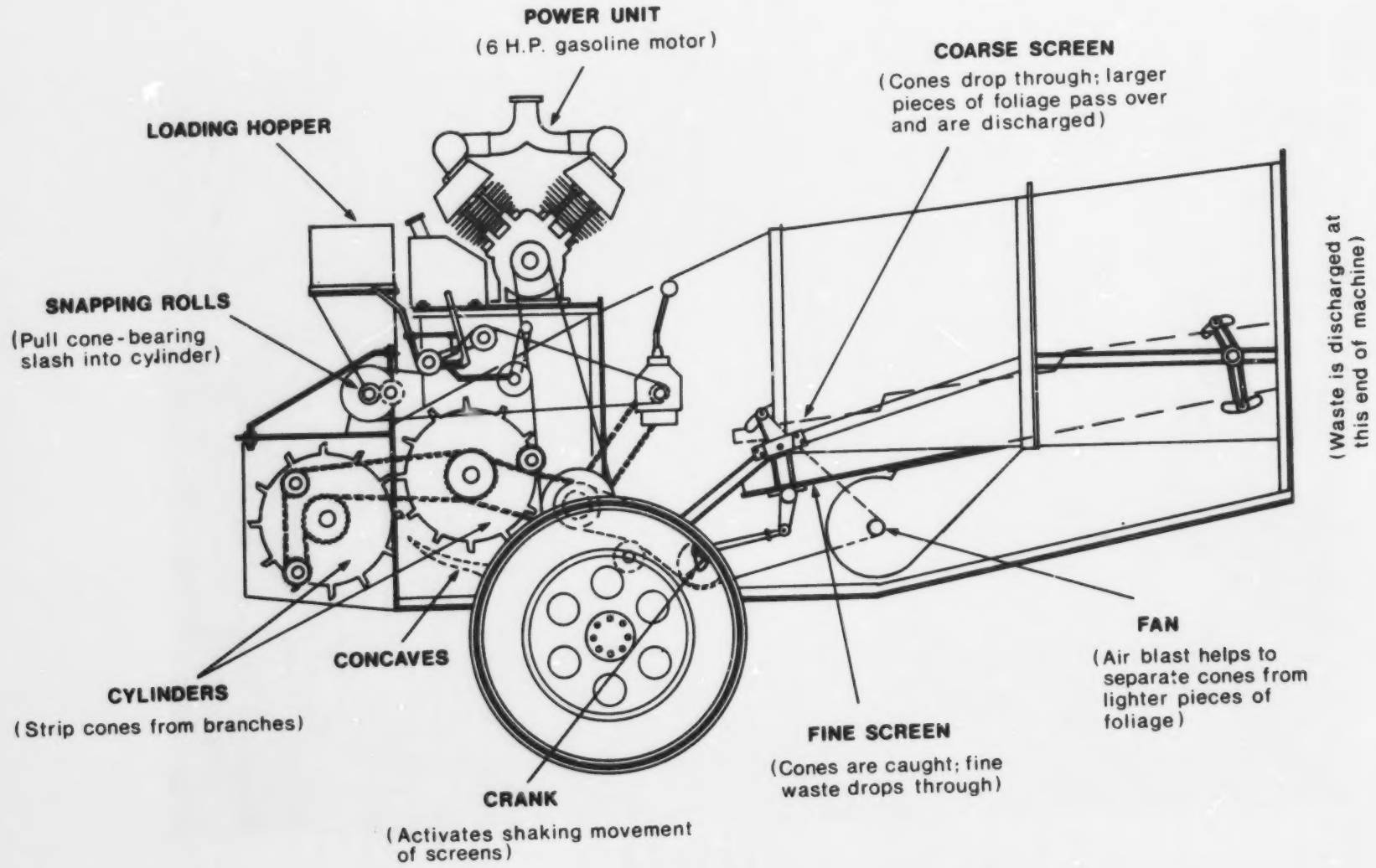
POWER UNIT
(6 H.P. gasoline motor)
COARSE SCREEN
(Cones drop through; larger pieces of foliage pass over and are discharged)
LOADING HOPPER
SNAPPING ROLLS
(Pull cone-bearing slash into cylinder)
(Waste is discharged at this end of machine)
FAN
(Air blast helps to separate cones from lighter pieces of foliage)
CONCAVES
CYLINDERS
(Strip cones from branches)
FINE SCREEN
(Cones are caught; fine waste drops through)
CRANK
(Activates shaking movement of screens)

Figure 1. "Mechanoconer II", a Case combine adapted for processing cones from branches (schematic view from Haig [1969]).

attack on the problem was launched cooperatively by GIFRC and the Ontario Ministry of Natural Resources (OMNR), with a committee of experts under the leadership of A. Citro, OMNR, providing guidelines. Heathwood Engineering Associates Ltd. of Kirkland Lake, Ontario was contracted to study the options, then develop and test effective equipment and systems for cone collection and processing.

A hypothetical methods analysis[2] indicated relative costs of several alternatives for meeting Ontario's black spruce seed requirements (Table 1).

Table 1. Estimated costs of several cone collecting methods.

Method	Labor (man-days)	Cost of cones ($ per hl)	
Hand picking	36,585	65	
Hand rake	7,500	15-38	
Powered rake	1,875	11	(equipment to be developed)
Combine	5	7.50	(equipment to be adapted)
Central plant	212	13	(equipment to be adapted)

It was decided that a modified agricultural combine was the likeliest machine for the cone separation job because it incorporates the essential mechanical functions, is readily available in a number of configurations and is mobile and self-powered in some models. The main modifications required were a destemming device to strip cone-bearing branches from the tops, and a cylinder with teeth or spring tines rather than the rubbing bars used for grain. (The cylinder's function is to detach cones from twigs.) The screening, cleaning and conveying functions of the combine did not need to be altered appreciably.

PREFERRED MECHANICAL APPROACH

The chosen solution[4] was a combination of different machinery to handle separate functions as follows:

1. Top stripper—a machine was developed to remove the twigs and cones from the stem top, which is too coarse for the combine. It consists of a cutting head to cut off branches at the stem and a set of pinch rolls to pull the stem through, butt first. The cutter knives are fixed for a diameter of 5 cm. A 5-hp gasoline engine with a pulley system powers the machine, which weighs over 100 kg. Two men can operate the unit, placed either on a pickup truck box or on a stand (Fig. 2).

4 Smith, E.P. and Woodcock, W.R. 1980. The implementation of a collecting and combining system for harvesting black spruce cones. Heathwood Eng. Assoc., Kirkland Lake, Ont. (unpubl. rep.)

Figure 2. Heathwood's top stripping machine, unmodified (from Smith and Woodcock, see footnote 4).

2. Conveyor--A "Little Giant" chain and paddle conveyor was used to load cone-laden branches onto a chuck wagon or truck. The stripping machine can be located over the conveyor hopper, thereby eliminating extra handling of branches.

3. Chuck wagon--A John Deere Model 110 CW self-unloading wagon was acquired to transport stripped branches and feed the combine feedbelt. For direct feeding into the combine, the small cross conveyor of the wagon should be extended by 1 m. A tractor with a PTO is required to power the chuck wagon.

4. Combine--For the cone separation and cleaning functions, a 25-year-old Allis-Chalmers Allcrop 60 harvester was used. It was modified to be self-powered by mounting a four-cylinder Ford engine on the drawbar (Fig. 3). Though towable on highways, this particular model requires a wide load permit. It can handle effectively branches up to about 1 cm in diameter. The combining operation involves a minimum of three men--to feed, tend the machine and handle bagged cones fed by chute from the machine. Daily maintenance is important, including cleaning, tightening chains and belts and lubricating fittings.

In field tests conducted in winter, the stripping machine, operated by two men, handled up to 400 tops per hour, averaging 200 if down time is considered. Comparative tests of manual stripping by Sandvik tool or hatchet produced 70 to 110 tops per hour. Problems of design and safety were encountered with the prototype stripper, and modifications were necessary. The combine with three or four men processed an average of 1,200 tops per hour during operating hours, producing .82 to 1.15 L of cones per top. In very cold weather, the canvas feed belt (lower draper belt) tended to stiffen and slip on its drive roller, requiring pre-heating with a torch. In operation, the chuck wagon proved to be efficient for collecting stripped branches and feeding the combine. As Table 2 indicates, the highest cost factor is manual top gathering; a casual trial showed that this can be reduced by using a skidder towing a Bombardier trailer or stoneboat to transport local accumulations of tops to the roadside. The trailer can handle 300 tops per load.

Table 2. Operating costs of Heathwood semi-mechanized cone collection tests[a].

		Cost per hl of cones ($)			
Test	No. of tops	Manual top gathering	Hand stripping	Combining	Total
1	13,000	40.60	23.80	3.30	67.70
2	12,000	24.80	12.00[b]	12.30[c]	49.10

[a] Summarized from Smith and Woodcock (see footnote 4).
[b] Lower because one-third of tops were stripped by machine, the remainder by hand.
[c] Higher because of cold weather problems.

Figure 3. Heathwood's Allis-Chalmers combine adapted for black spruce cone processing (from Smith and Woodcock, see footnote 4).

MESHING CONE AND TIMBER HARVESTING

The method of gathering tops and the mechanized cone processing system used should match the pulpwood logging system in place. There are various combinations of options, manual and mechanical. Gathering tops is the most critical job; the options available for various logging systems are shown in Figure 4[4]. In chainsaw-skidder and shortwood harvester operations, tops should first be accumulated in small local piles at the cutting site, then centralized at roadside landings either by hand or by skidder plus trailer. Alternatively, the local piles can be hand stripped and the branches bagged for delivery to the roadside. In feller-buncher operations, tops can be gathered at the bunched tree piles on the cutting site or at the roadside, although the skidding, delimbing and slashing operations at the road pose problems in top accessibility and cone loss. The feller-forwarder cuts, loads and moves full trees to roadside in one operation, limiting top gathering to the roadside site.

Field tests on cut-and-skid operations resulted in a top gathering rate of 60 tops per man-hour. In very cold weather, top collection proved impracticable because the brittle tops disintegrated from felling impact and skidding action. In feller-forwarder and feller-buncher operations, top collection rates ranged from 86 to 180 per man-hour.

Branch stripping can be handled manually at the cutting site or mechanically at the roadside. The latter is more cost-effective, particularly if tops are centralized at the combine site, allowing a fully mechanized stripping-feeding-combining operation. This would require about four stripping machines to provide continuous supply to the combine. Stripping at intermediate roadside locations between cutting site and combine site may be more applicable in some situations but it means more material handling, and hence higher cost.

Flexibility is the keynote in view of the wide variation in logging systems, accessibility, concentration of tops and annual cone crops.

AN ALTERNATIVE MACHINE

Between 1979 and 1981, staff of the Hearst District, OMNR, assisted by V.F. Haavisto of GLFRC, developed a different cone harvesting machine termed the "Hearst Machine", a combination of top stripper and cone separator mounted as a mobile unit[5]. A prototype was constructed from various remodelled equipment including a Bombardier swamp buggy trailer, a hammermill powered by a 7.5-hp Briggs and Stratton motor, a muck shaker and screen, a furnace-type blower and a 12-kw diesel generator to run the electric motors on the shaker and blower (Fig. 5). This rig, pulled by an M-6 muskeg tractor, was tested at the cutting site of a feller-buncher operation. It processed 100-120 tops per machine hour, about 1 hl of cones per hour, at an estimated cost of $80/hl; 77% of the production by volume was cones and 23% brush and debris.

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[5] Commanda, E. 1981. Portable cone harvester developed August '79 to November '81. Ont. Min. Nat. Resour., Hearst District. (unpubl. rep.)

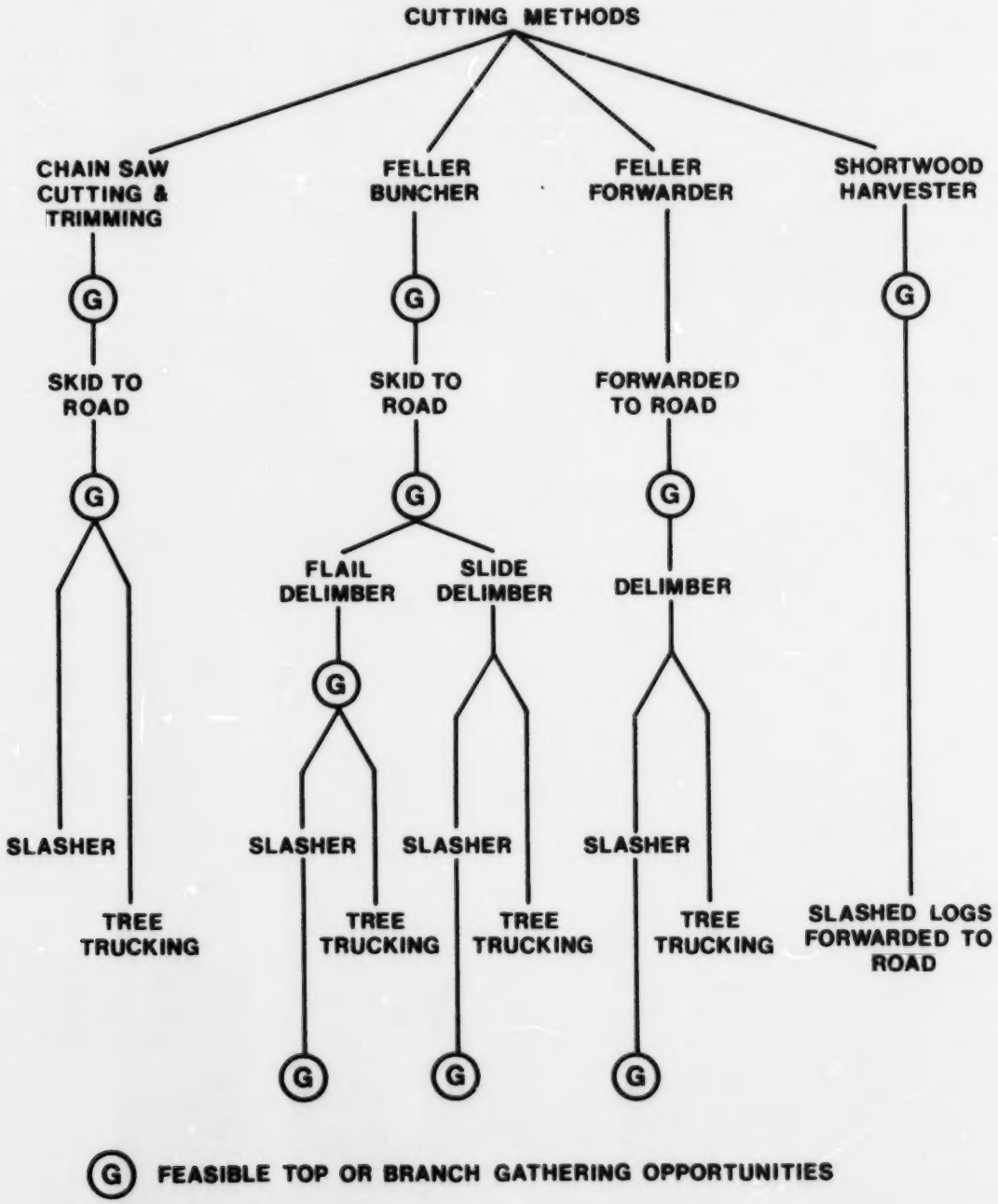

Figure 4. Top gathering options for four logging systems (from Smith and Woodcock, see footnote 4).

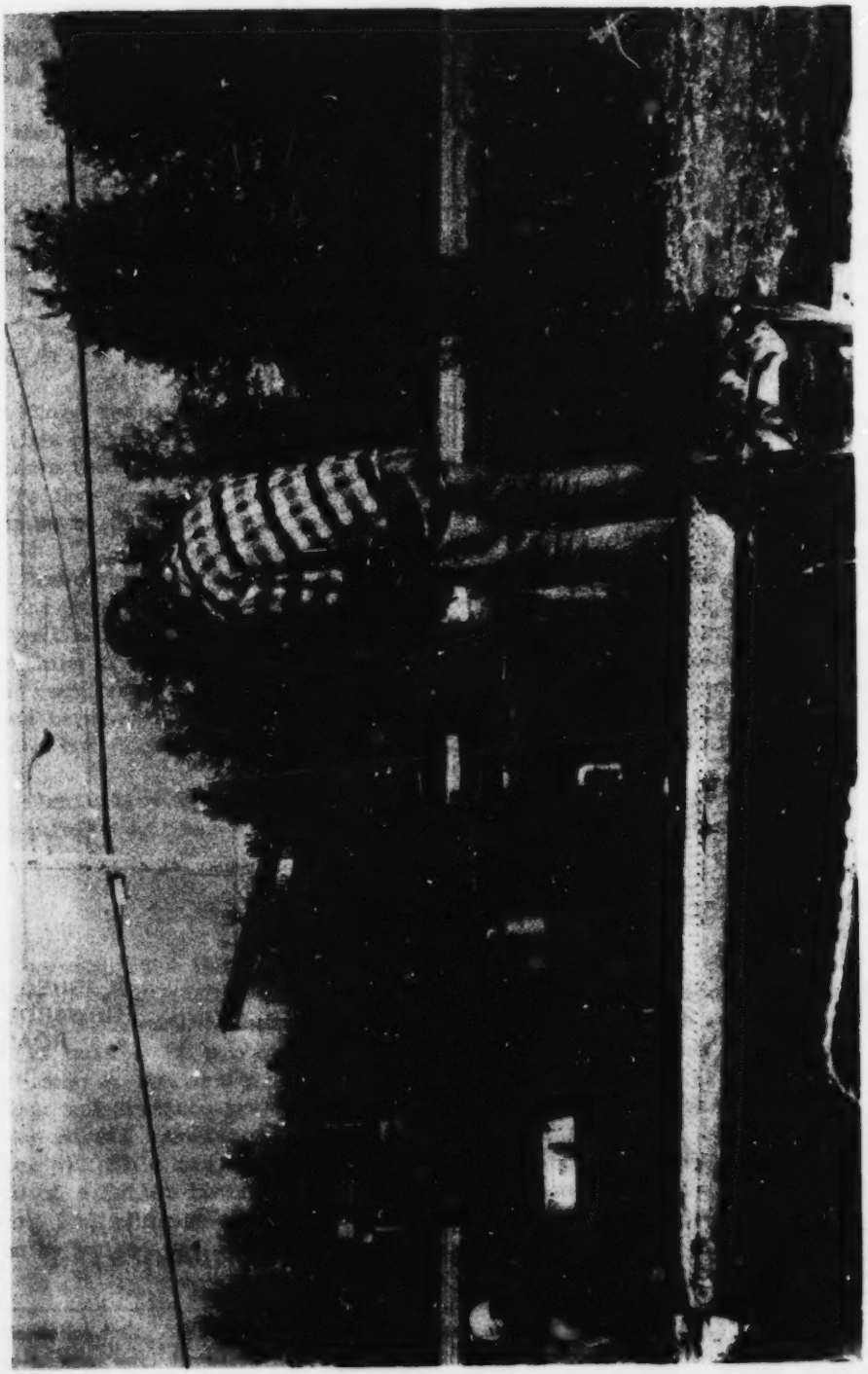

Figure 5. The "Hearst Machine" cone processor (from Commands, see footnote 5).

Subsequently several modifications were made. The electrical motors and generator were replaced by a 9.5-hp Briggs and Stratton engine providing power to the shaker and blower by line shafts and pulleys. A hydraulic feed, based on a pressure roller system powered by a two-way hydraulic motor, was added. The shaker screen was modified for quicker clearing. An operational test involving over 15,000 tops showed an average production of 138 tops processed per hour. Total costs were high--$1.03 per top and $184 per hl of cones--because the top gathering rate was only 24 tops per man-hour, the current cone crop was light (0.56 L per top) and travel and lost time were significant. Hence, this test was not representative of the machine's capability.

Further modifications included adding a small 2.5-hp Briggs and Stratton engine to allow separate control of the shaker assembly, and replacing the steel blades of the hammermill with a chain flail to reduce cone damage. Two tests were run with purchased tops from two different sources. Machine processing rates were 155 vs 112 tops per hour at .75 vs 1.92 L of cones per top; respective cone costs were $147.16 and $38.74 per hl. Obviously cone density per top was a major cost factor here.

In operation, a second pass of the material through the shaker-blower system reduced the debris content to 10%.[6] In another test[7] the "Hearst Machine" failed to work adequately as a stripper because the tops involved were too short, and as a result there was stemwood in the combine and the combine samples were especially dirty.

DIFFERENT STRIPPERS

At Kapuskasing, the OMNR staff, encountering problems of low productivity and safety with the Heathwood top stripper, decided to try portable brush chippers as strippers. Three makes of chippers were tested[3]; the results are given in Table 3.

Table 3. Comparison of three chippers and the top stripping machine.

	Woodchuck chipper	Eegar Beever chipper	Whisper chipper	Top stripping machine
Tops per man-hour	556	189	440	53-76[a]
Cost per top	$0.014	$0.04	$0.02	$.10-.14
Machine price	$15,500	$17,000	$14,464	-

[a] With improved blades

[6] Knight, W. 1982. Portable cone harvester, 1981-82 cone collection report. Ont. Min. Nat. Resour., Hearst District. (unpubl. rep.)

[7] Smith, E.P. 1982. Top stripping machine problems. Heathwood Eng. Assoc., Kirkland Lake, Ont. (unpubl. rep.)

The chippers, operated by two men, were effective in disintegrating tops and hence in stripping cones, and demonstrated the additional advantage over the top stripping machine of being able to handle any size of top. The Woodchuck and Whisper chippers were similar in performance, producing acceptable material that, when combined, yielded 75-80% clean cones, 13-21% of which were damaged.

On the basis of these tests and costs, the Kapuskasing office purchased an Asplundh "Whisper Chipper Series JEY 12" for use with a combine in large-scale harvesting operations.

Meanwhile, others in OMNR continued to try to improve the Heathwood Top Stripper to provide a customized, relatively inexpensive machine for this specialized seasonal job. The equipment development unit of OMNR at Maple, Ontario under A. Citro designed and produced stronger cutting heads of several sizes and an expandable vertical roller feed arrangement that, together with other housing changes, ensured operator safety. Implementing these modifications, J. Reid of the Thunder Bay Forest Station supervised the building of several new stripping machines (Fig. 6).

Figure 6. Modified stripping machine.

VERSATILE OPERATING SYSTEMS

No system of black spruce cone collection will apply generally, but numerous variations and combinations have been tested, providing useful guidelines. Woodcock[8], applying field test data and common assumptions to several simulated situations, produced the following analysis of alternatives.

In all situations, piles of tops at cutting sites are handled by crews with skidder and trailer. Transportation costs include moving tops to the stripping and harvesting sites and moving cones to headquarters. Harvesting costs include stripping and combining. A crew living cost, based on a remote work site with camp facilities, is applied. The combine wins over the hammermill harvester (Hearst Machine) because the latter incurs higher harvesting costs--lower machine capacity, hence more machines and workers--plus a 20% higher cone loss (Table 4).

Table 4. Costs of cone collection systems (less cost of tops).

System	Cost per hl of cones ($)			
	Harvesting	Transportation	Camping	Total
Hammer mill at cutting site	$35	26	16	77
Hammer mill at gravel road	33	30	17	80
Combine only at gravel road	12	24	9	45
Combine and stripping machine at gravel road (centralize top collection and skidder-trailer operation)	12	40	12	64
Combine and stripping machine at gravel road (centralize top collection and skidder-trailer/ truck operations)	12	24	9	45
Combine at Hearst headquarters	12	25	5	42

A good example of mass production through centralized processing is described by Smith[7]; 40,000 purchased tops were delivered by van to the Thunder Bay Forest Station, and unloaded by a small front-end loader onto a staging table behind four top-stripping machines, each operated by one man. Stripped branches travelled automatically by conveyor and elevator to a surge bin, then directly into a combine run by two men. This system produced a very clean cone sample.

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8 Woodcock, W.R. 1982. An efficiency study of black spruce cone collecting operations. Heathwood Eng. Assoc., Kirkland Lake, Ont. (unpubl. rep.)

As to top gathering, the most laborious and expensive step in the cone collection process, various options have been compared operationally.

At Kapuskasing in a large 1981-1982 operation involving some 64,000 tops, OMNR[3] tried top collection by its own staff, by private contract, through negotiation with a pulp and paper company and through advertised public purchase. The open purchase system worked best, with an excellent response and the lowest cost--$.75 per top or, alternatively, $150 per hl of hand-picked cones. Costs of other top collection methods were considerably higher, with the result that the overall average for the operation was $1.06 per top. Centralized cone processing costs amounted to $.71 per top for top stripping, mainly by chipper, and for cone processing, by an Allis-Chalmers Gleaner corn machine. Normal seed yield from hand-picked new cones is 417,000 viable seeds per hl of cones, but this mechanized processing operation, involving considerable numbers of old and damaged cones, provided only about 40% of the normal yield. Public purchase of tops or cones was chosen as the principal operating method for the future. Standards are necessary--in this case, tops were required to have a minimum of 100 cones for full payment; substandard tops were discounted by half or more.

In the same season, the Hearst District of OMNR collected and mechanically processed over 20,000 tops using staff crews and open purchase. Payment for delivered tops, with a minimum of 100 cones or .75 m length, was $.75 each. Cone yields from two sources were .8 and 1.4 L per top, or 125 and 71 tops per hl of cones, respectively. Processing by the Hearst Machine cost an estimated $75 per hl and the total cost per hl of cones was $151.14[6].

Young[9] describes a relatively small but efficient operation in the Sioux Lookout District of OMNR in the winter of 1982-1983. Silvicultural staff collected tops from a full-tree logging operation, stored them at a field camp and later trucked them to headquarters for processing by two Heathwood top stripping machines and a used International Harvester combine, Model 93. The final cost of processed cones, excluding capital costs, was $102.66 per hl, 80% of which was for top collection.

Young recommends several improvements in mechanizing the material handling segments of cone harvesting systems. The use of reefer vans (5th wheel trailers) is advocated to store tops collected in the field or purchased at local depots and to transport tops or branches to a central processing site. Figure 7 shows a layout utilizing belt conveyors for automated efficiency and minimal cone loss. The combine, which is not designed for use in sub-zero weather, should be stored in a heated building.

SUMMARY

It would appear that the mechanization of black spruce cone collection has been thoroughly examined and tested in all facets. The biggest expense is in

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[9] Young, J.H. 1983. Report on black spruce cone combine. Ont. Min. Nat. Resour., Sioux Lookout District. (unpubl. rep.)

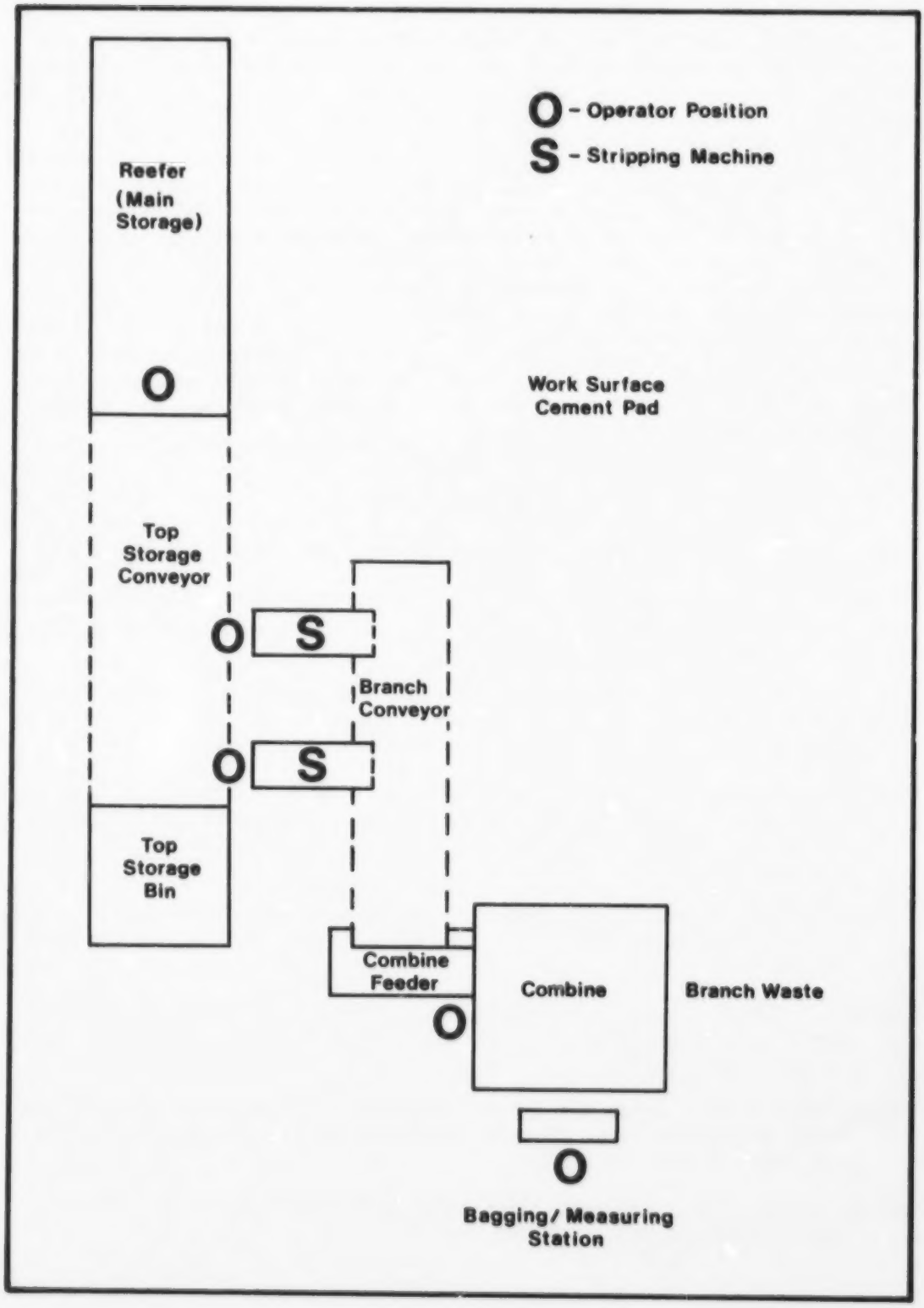

Figure 7. Cone harvesting process: future layout (from Young, see footnote 9).

gathering cone-laden tops from the logging site and moving them to the cone processing site. Experience has shown that this is best handled by public purchase of tops, based on advertised standards and prices. Matching the top gathering method to the logging system used is important, versatility being the key. Processing of the product (clean cones) from the tops can be mechanized efficiently with specialized equipment. Customized top stripping machines and standard brush chippers have proven effective for removing cone-laden branches from the stem. To separate and clean the cones, modified agricultural combines appear to be the answer. Various models including Case, Allis-Chalmers and International Harvester combines have been adapted successfully. Handling the large volumes of material involved can be expedited by judicious use of available equipment--skidders and swamp tractors for top gathering, reefer vans for top storage and transportation, and mobile conveyor systems for branch processing and feeding the combine. By these means, it is now feasible to undertake cone collection from hundreds of thousands of tops, regardless of whether the current crop is heavy or light. This will ensure a continuous seed supply for an expanding regeneration program.

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